Dryden Flight Research Center

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# Dryden Flight Research Center Handbook

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# Structural Design, Proof Test, and Flight Test Envelope Guidelines

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# STRUCTURAL DESIGN, PROOF TEST, AND FLIGHT TEST ENVELOPE GUIDELINES

## 1.0 PURPOSE

To provide guidelines for the structural design of experimental aircraft, aircraft structural components, and structural modifications to existing experimental aircraft operated at NASA DFRC. These guidelines account for structural instrumentation options, proof test options, and flight test operational envelope options, all of which impact the initial structural design approach.

## 2.0 DEFINITION OF TERMS

Limit Load: Represents the worst possible loading conditions the aircraft structure and/or structural component is expected to encounter while operating within its allowable flight envelope as defined by Mach number, altitude, air speed, weight, load factor, aircraft attitude, angular rates and accelerations, and control surface/flap deflections and deflection rates. No appreciable permanent deformation of the structure is allowed at limit load, and often local buckling is not allowed. Additionally, for loads up to limit load, the deformation of the structure shall not interfere with the safe operation of the aircraft.

Factor of Safety (F.S.): A number when multiplied by the Limit Load results in the Ultimate Load.

Ultimate Load: Determined by multiplying Limit Load by the Factor of Safety. Structural failure is not allowed at Ultimate Load.

Margin of Safety (M.S.): The ratio of excess strength to required strength (at ultimate load), or [(allowable load/stress)/(calculated load/stress)] -1. The Margin of Safety must always be zero or a positive number.

Allowable Load: The maximum load/stress that a structure or structural component can sustain before resulting in a failed condition. Examples of allowable loads are, yield and ultimate stresses of materials, yield and ultimate loads in redundant structural components, local and global buckling loads.

Calculated Load: Generally the ultimate load, ultimate stress, or buckling load. Can be the yield stress, especially for highly ductile materials, to insure no yielding below limit load. Composite materials add more complexity with bond loads/stresses and interlaminar shear.

## 3.0 BACKGROUND

NASA Dryden is engaged in flying many varied and unique aircraft. Frequently these aircraft require structural modifications in order to accommodate unique flight experiments; and sometimes a completely new one-of-a-kind experimental airplane is built. Whenever a new airplane, or one with substantial modifications, such as new lifting surfaces or new control laws, is flight tested, structural loads flight testing becomes an important element of the flight test program.

There are four distinct objectives associated with structural loads flight testing:

1. Acquire stress, load, temperature, and deflection data for verification of design predictions and analysis codes.
2. Expand the flight envelope of research aircraft to enable the acquisition of data required for performance, stability and control, propulsion, and any other disciplinary research objectives.
3. Demonstrate new structural materials and structural concepts in the flight environment.
4. Demonstrate that a prototype vehicle can perform all Military Standard or FAA Regulation maneuvers everywhere in the design flight envelope. This process is often referred to as "structural demonstration."

The first two objectives are the most common types of flight activity at NASA DFRC. The DFRC has been a leader in the development of flight load and deflection measurement techniques and has developed an experienced staff for generating analytical predictions, planning load buildup flights, monitoring loads in real time, and conducting post flight data analysis in support of safety of flight and for flight research documentation and reporting. These activities often involve evaluating new and unique configurations such as, forward swept wings, oblique wings, joined wings, advanced flexible wings, etc., which are too immature for commercial design applications when they are first committed to flight. Emphasis is placed on correlation with analytical and wind tunnel predictions and the development of new instrumentation and flight test techniques with a thorough understanding of the phenomena involved so that a dependable assessment of the generic technology can be developed.

The third objective occurs less frequently and generally involves little or no instrumentation. The materials and concepts are usually developed under contract to Langley Research Center or the Air Force and the responsibility for justifying their flight worthiness rests with contractors. These activities usually involve the design, analysis, and ground test of panels or small components, such as control surfaces, which are subsequently mounted on existing vehicles and flight tested.

The fourth objective is usually associated with satisfying a contractual procurement specification for a production aircraft. It is conducted by the airframe manufacturer using private or government facilities (AFFTC, NATC, Boeing Airfield, etc.), on an intensive flight test schedule. The airframe contractor assembles a special structural demonstration flight test team consisting of highly experienced structural flight test engineers backed up by the structural designers and analysts who designed and developed the airplane. The goal of this activity is to force a relatively mature configuration to the limits of its design envelope as soon as possible, thus demonstrating both the adequacy of the airplane structure and the predicted flight environment (aerodynamic flow field and airplane kinematic responses). This is one of the highest risk types of flight testing.

NASA Dryden has technical experience in the flight research environment, as depicted in items 1 through 3, and has little or no experience in structural demonstration flight testing, which is a strength of the AFFTC. Where the issue of a "structural demonstration" arises in joint programs with the Air Force, these programs should be conducted through a DFRC/AFFTC Alliance which operates under AFFTC regulations using AFFTC facilities whenever possible.

## 4.0 DESIGN GUIDELINES

Aircraft instrumentation, static ground proof tests, and a desired flight envelope are three major factors that interplay in establishing structural design guidelines. The following paragraphs present design criteria, instrumentation requirements, and proof test requirements that ultimately establish corresponding flight operational envelopes. These guidelines have been applied to past and present DFRC aircraft flight programs and are planned for application to future programs.

The integrated design criteria, proof-test and instrumentation requirements, and corresponding operational flight envelopes are graphically illustrated in figure 1.

4.1. Figure 1a defines the approach needed to satisfy the Military Standard 8860 for the design, testing, and qualification of military production aircraft. Typically, a factor of safety (F.S.) of 1.5 is used, i.e., Ultimate Load = 1.5 x Limit Load. A positive, or zero, margin of safety (M.S.) is maintained based on analysis, i.e., (Allowable Load/Stress - Calculated Load/Stress)/(Calculated Load/Stress) ≥ 0. The aircraft is fully instrumented for loads and stresses, i.e., strain gages are installed on all lifting surfaces, control surfaces, and the fuselage. The strain gages are calibrated for lifting surface loads, control surface hinge moments, and fuselage loads. Additional strain gages are installed for local stress measurements. A dedicated static test aircraft is fully instrumented (about 10 times the instrumentation of the flight test aircraft) and tested to ultimate load. The flight test aircraft is then used to perform flight structural demonstration tests to limit load to certify the aircraft. Once certified, all aircraft incorporating the same basic structural design and flight control laws are considered cleared to operate within the certified envelope without further testing.

4.2. Figures 1b, 1c, and 1d represent three approaches, or options, to design, test, and operate a "one-of-a-kind" aircraft or to modify existing aircraft, which have been previously certified per Military Standard or FAA Regulation.

4.2.1 Figure 1b illustrates Option 1. Typically, a factor of safety (F.S.) of 1.5 is used. However, a margin of safety (M.S.) of 0.25 is maintained, i.e., (Allowable Load/Stress - Calculated Load/Stress)/(Calculated Load/Stress) ≥ 0.25. No strain gage/loads instrumentation is installed and no proof tests are performed. The aircraft flight envelope is restricted such that 80% of the predicted design limit load of any part of the aircraft structure is not exceeded. Note that this restriction may require the aircraft to operate at load factors less than 80% limit. An example of this option is the AFTI/F-111 Mission Adaptive Wing leading edge and trailing edge devices.

4.2.2 Figure 1c illustrates Option 2. Typically, a factor of safety (F.S.) of 1.5 is used, and a positive margin of safety (M.S.) is maintained, i.e., (Allowable Load/Stress - Calculated Load/Stress)/(Calculated Load/Stress) ≥ 0. The aircraft is fully instrumented with calibrated strain gages, and the aircraft is proof tested to design limit load. The aircraft is cleared to fly to 80% of the proof tested load through a nominal envelope expansion process. Clearance may be given to fly to 100% limit load on a case by case basis. Examples of this option are the F-8 Supercritical Wing and the proposed F-8 Oblique Wing Research Aircraft.

4.2.3 Figure 1d illustrates Option 3. Typically, a factor of safety (F.S.) of 1.5 is used, and a positive margin of safety (M.S.) is maintained, i.e., (Allowable Load/Stress - Calculated Load/Stress)/(Calculated Load/Stress) ≥ 0. No loads instrumentation is installed and no proof tests are performed. The aircraft envelope is restricted such that 60% of the predicted design limit load of any part of the aircraft structure is not exceeded. There are no examples where this option was used.

Options 1 and 3 are generally used when modifying an aircraft that has already met Military Standard or FAA Regulation flight qualification requirements, and the modifications are simple with easily determined load paths, the design load predictions are easily derived or are known to be conservative, and component proof tests may have been conducted to verify the design concept in the laboratory. Option 1 is most often used because typical structural modifications to existing aircraft using the conservative design criteria do not result in a significant weight penalty, but does result in significant cost savings in avoiding instrumentation installations and proof tests. This option also provides a reasonable flight operational envelope. Obviously, not all aircraft designs or modifications can fall into options 1 or 3. Most of the one-of-a-kind research aircraft flown at NASA Dryden have used option 2 criteria.

## 5.0 REFERENCES

NASA Technical Standard; Structural Design and Test Factors of Safety for Spaceflight Hardware. NASA-STD-5001, June 21, 1996.

This standard establishes structural strength design and test factors and service life factors for spaceflight hardware development and verification. The standard was developed by a working group of structural engineers from most of the NASA Centers. The criteria are applicable to launch vehicles, including propellant tanks, solid rocket motor cases, and payloads. The standard also covers pressure vessels and addresses thermal stresses. The standard is suitable for application to experimental atmospheric flight vehicles.

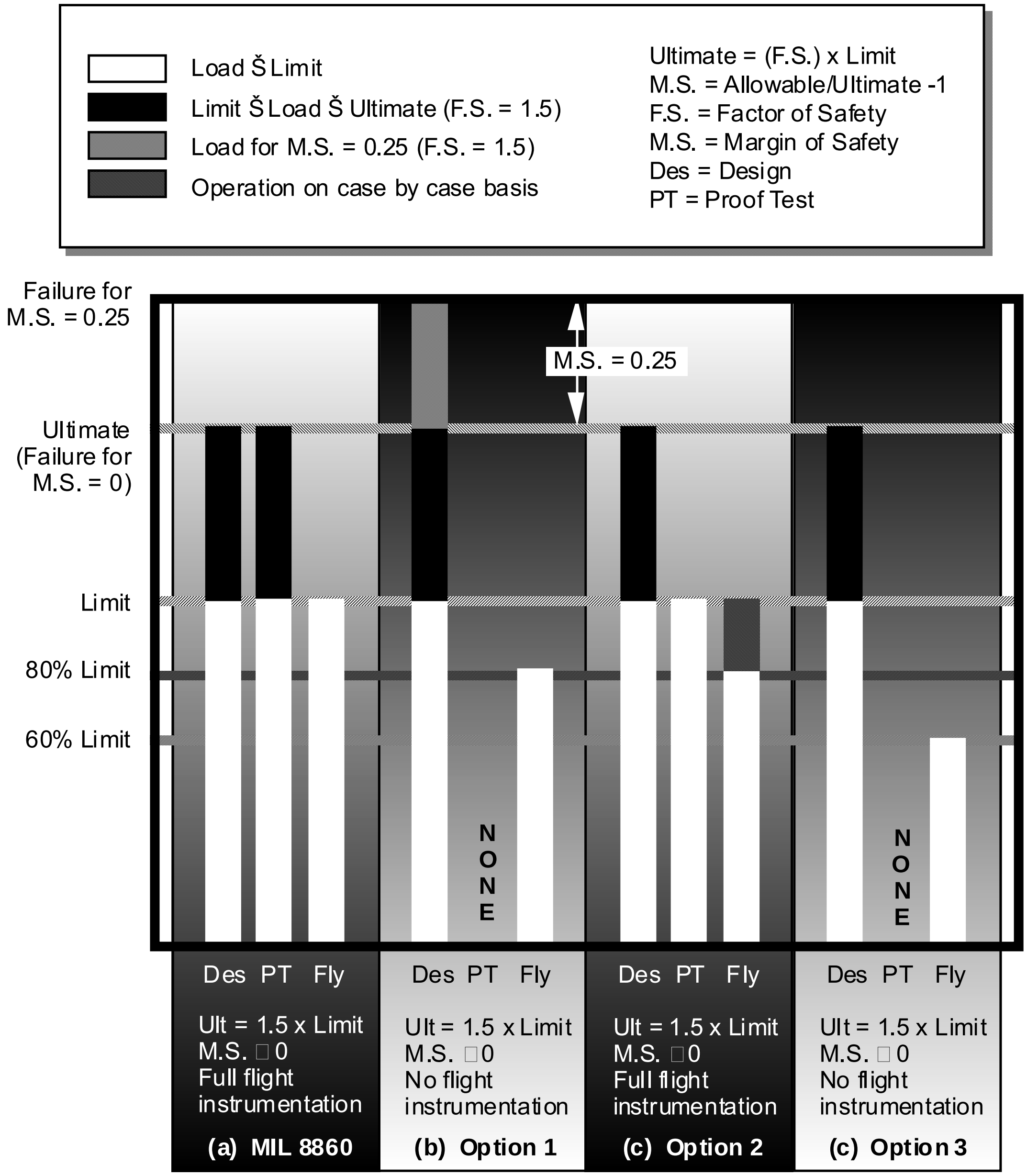


Figure 1. Comparison of MIL 8860 design criteria, instrumentation, proof test, and flight test requirements with three options for experimental aircraft.